DESIGN OF 2DF IMC CONTROLLER

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF

Bachelor of Technology in

Electronics and Instrumentation Engineering
Electronics and Communication Engineering

Under the Guidance of
Prof. T K DAN

By

GOPAL KRUSHNA PANDA
(110EI0246)

ANUBHAV PANIGRAHY
(110EI0083)

HEMANT KUMAR GUPTA
(110EI0414)

Department of Electronics & Communication Engineering
National Institute of Technology
Rourkela

2013-2014

NATIONAL INSTITUTE OF TECHNOLOGY
ROURKELA

CERTIFICATE

This is to certify that the project report titled "DESIGN OF 2DF IMC CONTROLLER" submitted by Gopal Krushna Panda (Roll No: 110EI0246), Anubhav Panigrahy (Roll No: 110EI0083) and Hemant Kumar Gupta (Roll No: 110EI0414) in the partial fulfillment of the requirements for the award of Bachelor of Technology Degree in Electronics and Instrumentation Engineering and Electronics and Communication Engineering during session 2010-2014 at National Institute of Technology, Rourkela (Deemed University) and is an authentic work carried out by them under my supervision and guidance.

Date:

Prof. T K DAN
Department of E.C.E
National Institute of Technology
Rourkela-769008

ACKNOWLEDGEMENT

I take this opportunity to express my profound gratitude and deep regards to my guide Prof. T K Dan for his exemplary guidance, monitoring and constant encouragement throughout the course of this thesis. The blessing, help and guidance providen by him time to time shall carry me a long way in the journey of life on which I am about to embark.

GOPAL KRUSHNA PANDA (110EI0246)

ANUBHAV PANIGRAHY (110EI0083)

HEMANT KUMAR GUPTA (110EI0414)

CONTENTS

5. SIMULATION RESULTS:

ABSTRACT

The Internal model control (IMC) relies on the mathematical model of the process to be controlled. In IMC we can achieve accurate control only if the control systems contain (either implicitly or explicitly) some mathematical representation of the process to be controlled. In this report we analyze about automatic process control, basic principle behind imc, and design 2df imc controller.

The 1df imc controller is good for set point tracking. But in case of disturbance rejection the time to settle is too high. In this case we use 2df imc controller. One controller is used for set point tracking and another is used for disturbance rejection. Two degree of freedom imc controller is always not use full. 2df imc controller is not use full for Process having frequency response initially low and then high. So before designing the controller for the process, we have to check and compare with the 1df output and then we should design controller for the process.

In case of 1df controller, we design filter parameter as our requirement to track the set point. Set point Controller is designed in such a way that it cancels out poles and zeroes of the process. So the controller is very good for set point tracking. But for the process having disturbance lag it is not useful. If we design the 1df controller for disturbance rejection it is not good for set point tracking. So we have to use another degree of freedom.

In our study we analyze different principle of designing the 2df imc controller and advantage of this over 1df controller.

List of Figures

Chapter 1

INTRODUCTION TO AUTOMATIC PROCESS

CONTROLLER AND 1DF IMC CONTROLLER

CHAPTER 1

1.1 Automatic Process Control

A conceptual process block diagram for a chemical process is illustrated in Figure 1.1. The inputs are categorized as either manipulated or disturbance variables and the responses are categorized as measured or unmeasured in Figure 1-1a. To automate the working of a process, it is necessary to use measurements of process responses or disturbance inputs to make decisions about the suitable values of manipulated inputs. This is the function of the controller illustrated in Figure 1-1b; the measurement and control signals are illustrated as dashed lines.

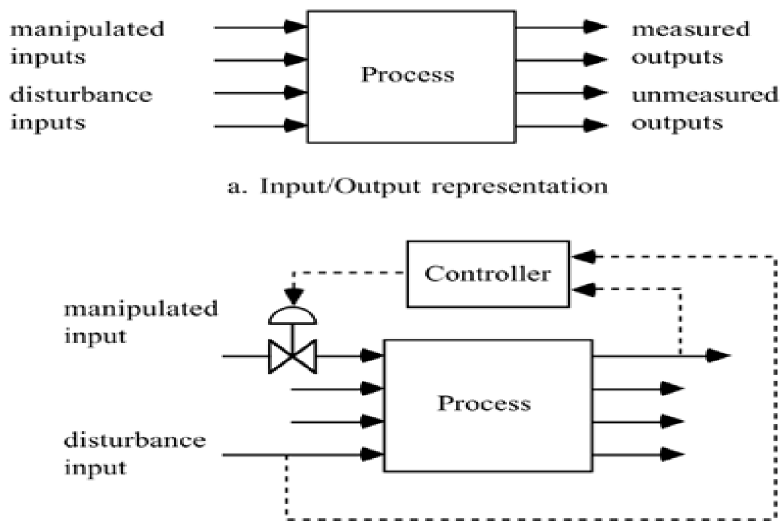


Figure 1-1. Conceptual process input/response block diagram.

The development of a control strategy comprises framing the following.

Control objective(s).

- Input variables— classify these as (a) manipulated or (b) disturbance variables; inputs may change continuously, or at discrete intervals of time.
- Response variables— classify these as (a) measured or (b) unmeasured variables; measurements may be made continuously or at discrete intervals of time.
- Constraints— classify these as (a) hard or (b) soft.
- Operating properties— classify these as (a) continuous, (b) batch, or (c) semi continuous (or semi-batch).

Safety, environmental, and economic considerations.

- Control structure— the controllers can be feedback or feed forward in nature.

Here we discuss each of the steps in formulating a control problem in more detail.

The first step of developing a control strategy is to frame the control objective(s). A chemical-process operating unit usually comprises several unit workings. The control of an operating unit is mostly brought down to considering the control of each unit working individually. Even then, every unit working may have multiple, sometimes contradictory objectives, so the development of control objectives is not an unnecessary problem.

Input variables can be categorized as manipulated or disturbance variables. A manipulated input is one that can be adjusted by the control system (or process operator). A disturbance input is a variable that influences the process responses but cannot be tuned by the control system. Inputs may change continuously or at discrete intervals of time.

Response variables can be categorized as measured or unmeasured variables. Measurements may be made continuously or at discrete intervals of time.

Any process has certain operating constraints, which are categorized as hard or soft. An instance of a hard constraint is a minimum or maximum flow rate—a valve operates between the extremes of fully closed or fully open. An instance of a soft constraint is a product structure—it may be desirable to specify a structure between certain values to sell a product, but it is possible to violate this specification without posing a safety or environmental hazard.

Operating properties are usually categorized as continuous, batch, or semi-continuous (semi-batch). Continuous processes operate for long phases of time under comparatively constant operating conditions before being "shut down" for cleaning, catalyst regeneration, and so on. For instance, some processes in the oil-refining industry operate for 18 months between shutdowns. Batch processes are dynamic in nature—that is, they usually operate for a short duration of time and the operating conditions may differ quite a bit during that phased of time. Instances of batch processes include beer or wine fermentation, as well as many specialty chemical processes. For a batch reactor, an initial charge is made to the reactor, and conditions (temperature, pressure) are changed to produce a required product at the end of the batch time. A distinctive semi-batch process may have an initial charge to the reactor, but feed components may be added to the reactor during the duration of the batch run.

Another necessary consideration is the dominant timescale of a process. For continuous processes this is usually related to the residence time of the vessel. For example, a vessel with a liquid volume of 100 liters and a flow rate of 10 liters/minute would have a residence time of 10 minutes; that is, on the average, an element of fluid is retained in the vessel for 10 minutes.

Safety, environmental, and economic considerations are all very necessary. In a way, economics is the decisive impelling cause—an unsafe or environmentally harmful process will eventually cost more to operate, through fines paid, insurance costs, and so on. In numerous industries (petroleum refining, for example), it is necessary to minimize energy costs while producing products that meet certain requirements. Better process automation and control allows processes to operate closer to "optimum" conditions and to produce products where variability requirements are fulfilled.

The concept of "fail-safe" is always necessary in the choice of instrumentation. For instance, a control valve needs an energy source to move the valve stem and change the flow; most often this is a pneumatic signal (usually 3–15 psig). If the signal is lost, then the valve stem will go to the 3-psig limit. If the valve is air-to-open, then the loss of instrument air will cause the valve to close; this is known as a fail-closed valve. If, on the other hand, a valve is air-to-close, when instrument air is lost the valve will go to its fully open state; this is known as a fail-open valve.

.

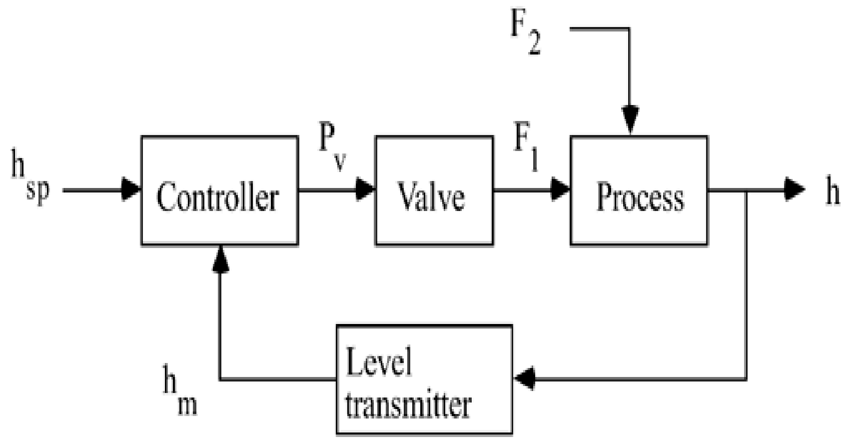


Figure 1-2. Conceptual process block diagram.

1.2 Overview of Model-Based Controller

Process models are used in each of the layers of the hierarchical structure. In the regulatory control layer, models are employed in the tuning of PID and internal model controllers (IMCs), the design of feedforward, cascade, and override controllers, and the design of inferential controllers (control using secondary measurements). In the dynamic optimization layer, models are used to predict the behavior of the process into the future, to compute control actions, and to determine local economic optimum point providen process constraints. Nonlinear steady-state models are used in the real-time optimization layer to compute steady-state optimum operating conditions. Linear models of the overall plant operating properties are used in the scheduling and planning layers.

In this book we will focus primarily on the use of models in regulatory and dynamic optimization layers.

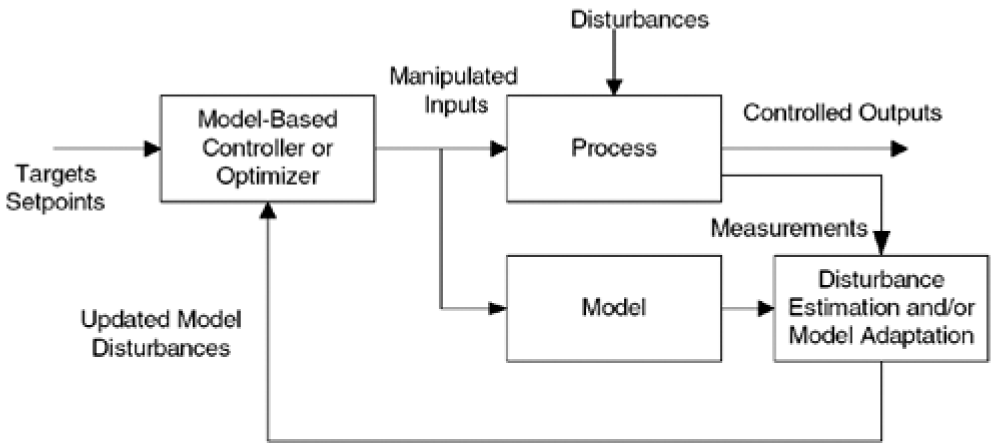


Figure 1-3. 1df Imc controller block diagram

The process model: This block computes predicted values of the process measurements.

Disturbance estimation/model parameter adaptation: This block does adjustments to the disturbance estimate or model parameters so that the predicted values are brought closer to the actual measurements.

Controller or optimizer: This block computes the actions needed so that the chooseed

responses of the process will be driven to their required or optimum setpoints, while removing constraint violations.

1.3 Introduction to 1DF IMC

In process control, model based control systems are mainly used to get the required set points and ignore minute external disturbances. The internal model control (IMC) design is based on the fact that control system contains some representation of the process to be controlled then a perfect control can be achieved. So, if the control architecture has bee developed based on the exact model of the process then perfect control is mathematically possible.

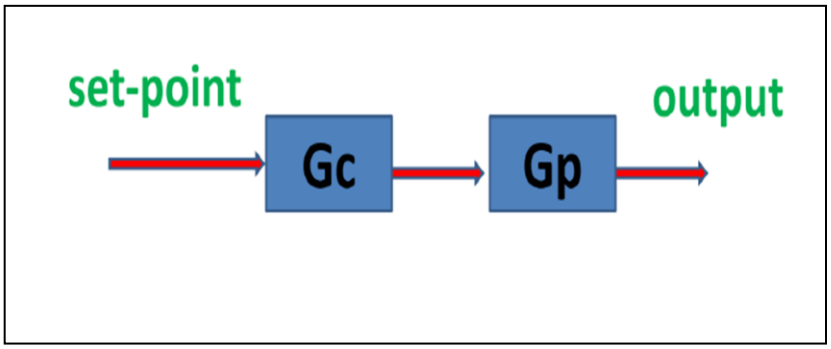


Figure 1-4. 1df Imc controller basic principle

Response = C* P* Set-point

C = controller

P= actual process

p* = process model

C =inverse of p*

If **p = p*** (the model is the exactly same as the actual process) Response is:

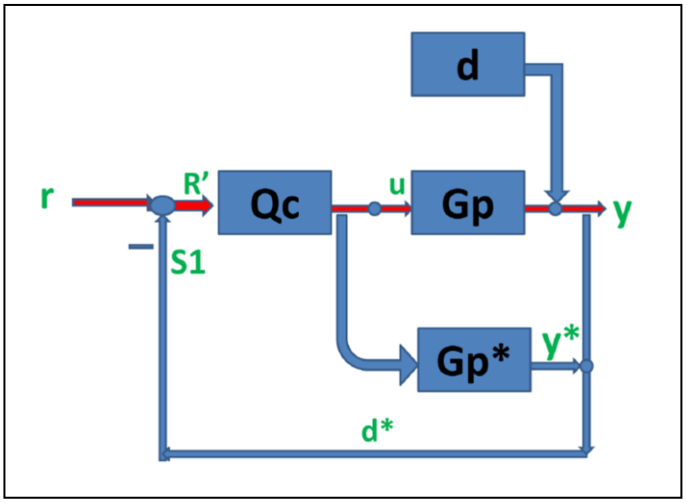
Y(s) = C* P* Set-point

= Setpoint

The response will be equal to the set point

The exceptional characteristic of IMC structure is including the process model which is parallel to the actual process or the plant. Here "*" has been used to represent signals associated with the model.

Figure 1-5. 1df Imc controller with feed back



The different parameters used in the IMC basic structure illustraten above are as follows: C= IMC

P= actual process

P*= process model r= set point

r"= modified set point

u= manipulated variable (controller response)

d= disturbance

d*= calculated new disturbance y= measured process response

y*= process model response New calculated disturbance: d*= (P - P*)u +d Modified set-point:

r‘‘= r- d*= r- (P - P*) u – d

Now we consider a different case **Perfect model without disturbance:** A model is said to be perfect if Process model is same as actual process i.e. **p = p***

no disturbance implies **d = 0**

Thus relationship between the set point (**r**) and the response (**y**) **is y = p . c .r**

This relationship is same for as for open loop system. Thus if the controller C and the process P are stable the closed loop system will be stable.

But in practical cases always the disturbances and the uncertainties do exist hence actual process or plant cannot be equal to the model of the process.

The error signal **r'(s)** comprises of the model mismatch and the disturbances which is send as modified set-point to the controller and is providen by

r'(s) = r(s) – d*(s)

And response of the controller is the manipulated variable **u(s)** which is send to both the process and its model.

u(s) = r‘‘(s) *Qc(s) = [r(s) – d*(s)] Qc(s)

= [r(s) – {[P(s) – P*(s)].u(s) + d(s)}] . Qc(s)

u(s) = [[r(s) – d(s)] *Qc(s)] / [1 + { P(s) – P*(s) } Qc(s)] But

y(s) = P(s) * u(s) + d(s)

Hence, closed loop transfer function for IMC is

y(s) = {Qc(s) . P(s) . r(s) + [1 – Qc(s) . P* (s)] . d(s)} / { 1 + [P(s) – P* (s)] Qc(s) }

Also to improve the robustness of the system the effect of model mismatch should be minimized. Since mismatch between the actual process and the model usually are seens at higher frequencies of the systems frequency response, a low pass filter f(s) is added to prevent the effects of mismatch. **Thus the internal model controller is designed as inverse of the process model which is in series with the low pass filter** i.e.

Q(s) = Qc(s)*f(s)

The order of the filter is chosen to make it proper or at least semi proper (such that order of numerator is equal to the order of denominator). The resulting closed loop then becomes

y(s) = {Q(s) . P(s) . r(s) + [1 – Q(s) . P* (s)] . d(s)} / { 1 + [P(s) – P* (s)] Q(s) }

CHAPTER 2

IMC DESIGN PROCEDURE

2.1 Introduction

The IMC design procedure is exactly the same as the open loop control design procedure. Unlike open loop control, the IMC structure compensates for disturbances and model uncertainties. The IMC filter tuning parameter “lem” is used to remove the effect of model uncertainty. The normal IMC design procedure focuses on set point responses but with good set point responses good disturbance rejection is not assured, especially those are seen at the process inputs. A modification in the design procedure is proposed to enhance input disturbance rejection and to make the controller internally stable.

2.2 IMC design procedure

Consider a process model P*(s) for an actual process or plant P(s). The controller Qc(s) is used to control the process in which the disturbances d(s) enter into the system. The different steps in the Internal Model Control (IMC) system design procedure are:

2.2.1FACTORIZATION

It includes factorizing the transfer function into invertible and non invertible parts. The factor containing right hand poles, zeros or time delays become the poles when the process model is inverted leading to internal stability. So this is non invertible part which has to be take outd from the transfer function. Mathematically, it is providen as

P*(s) = P+* (s) P-* (s)

P+* (s) is non-invertible part

P-* (s) is invertible part

There are two methods of factorization:

(i) Simple (ii) All pass

Usually we use all pass factorization where the unstable RHP is compensated by a mirror image of it on the left hand side.

2.2.2 IDEAL IMC CONTROLLER

The ideal IMC is the inverse of the invertible part of the process model. It is providen as

$Qc^*(s) = inv\ [P_-^*(s)]$

2.2.3 ADDING FILTER

Now a filter is added to make the controller at least semi-proper due to a transfer function is not stable if it is improper.

A transfer function is known as proper if the order of the denominator is greater than the order of the numerator and for exactly of the same order the transfer function is known as semi- proper.

So to make the controller proper mathematically it is providen as

$Q(s) = Qc^*(s)\ f(s) = inv\ [\ P_-^*(s)]\ f(s)$

2.2.4 LOW PASS FILTER f(s)

We know to reduce the uncertainty at higher frequencies a filter is added and the resulting controller is providen as:

$Q(s) = Qc^*(s)\ .f(s) = \{inv\ [\ P_-^*\ (s)]\}\ f(s)$ Where

f(s)= 1/(lem* s+1) ^ n

Where *lem* is the filter tuning parameter which varies the speed of the response of the closed loop system. When *lem* is minuteer than the time constant of the first order process the response is faster.

The low pass filter is of three types:

a) For input as set point change, the filter used is f(s) = 1/(lem* s+1) ^ n

here **n** is the order of the process.

b) For tracking ramp set point changes the filter used is

f(s) = (n. lem. s + 1)/ (lem* s+1) ^ n

c) For good ignoreion of step input load disturbances the filter used is

f = (gamma.s+1)/(lem* s+1) ^ n

where gamma is a constant.

2.3 IMC design for 1st order system

Now applying the above IMC design procedure for a first order system:

- **Providen process model for 1st order system : P*(s) = Kp*/[Tp*(s)+1] Kp=1 and Tp=10**

P*(s) = P+* (s) . P-* (s) = 1 .(Kp*/[Tp*(s)+1]) Qc*(s) = inv[P-* (s)] = [Tp*(s)+1] / Kp*

Q(s) = Qc*(s). f(s) = [Tp*(s)+1] / [Kp*. (lem(s) + 1)]

f(s) = 1 / (lem* s + 1)

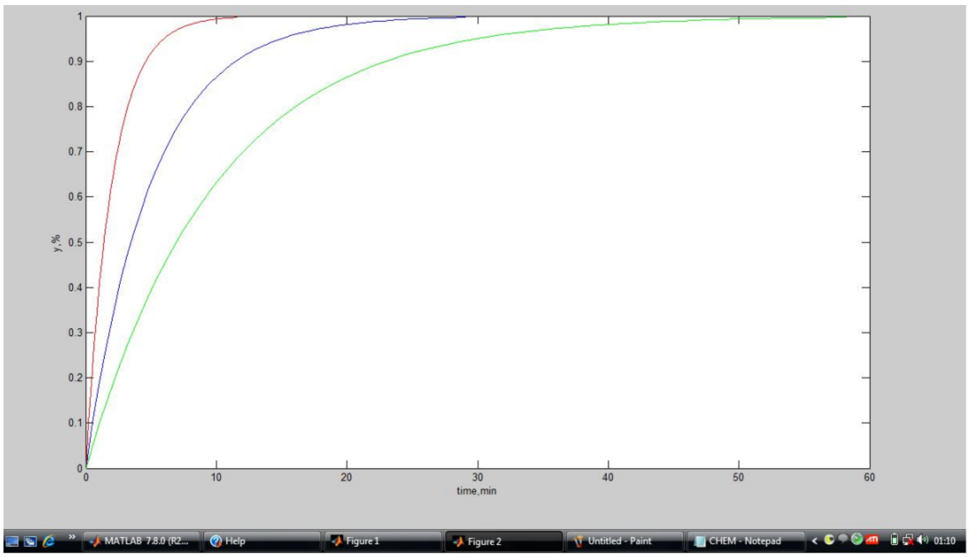
y(s) = Q(s). P(s).r(s) = P+* (s) . f(s). r(s) Response variable:

y(s) = r(s)/(lem*s +1)

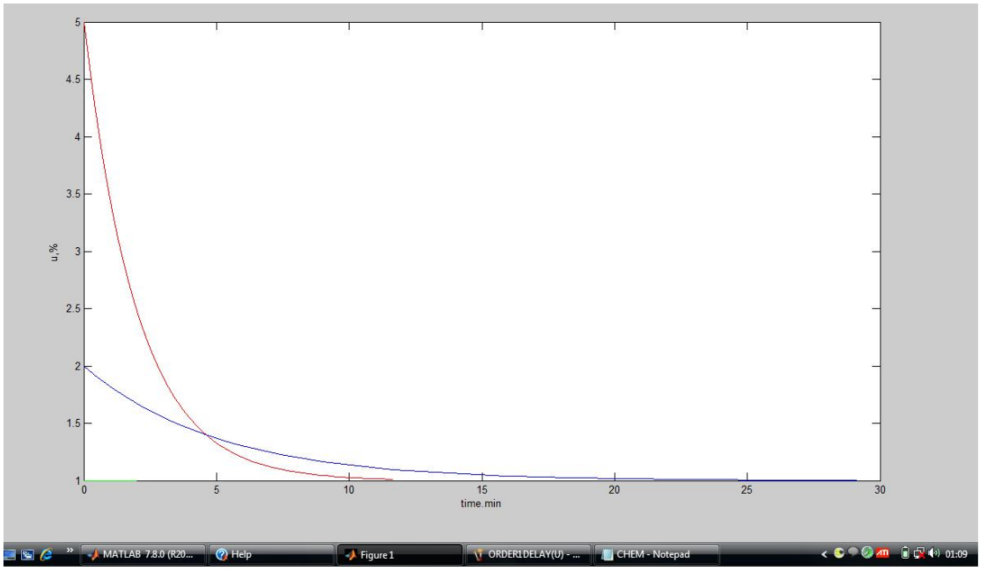
- Manipulated variable:

u(s) = Q(s) . r(s) = [[Tp*(s)+1].r(s)]/ [Kp. (lem. s +1)]

2.3.1 Simulation plot for IMC 1st order system **a) Response variable response**



b) Manipulated variable response


u,%
time,min
5
4.5
4
3.5
3
2.5
2
1.5
1
0
5
10
15
20
25
30
MATLAB 7.8.0 (R20...
Help
Figure 1
ORDER1DELAY(U) - ...
CHEM - Notepad
01:09

2.4 IMC design for 2nd order system

- **Providen process model for 2nd order system: P*(s) = [-9s + 1] / [(15s +1) (3s + 1)]**
- P*(s) = P+*(s) . P-* (s) = [(-9s + 1)/(9s + 1)] *[[9s + 1] / [(15s +1) (3s + 1)]]
- Qc*(s) = inv[P-* (s)] = [(15s +1) (3s + 1)] / (9s + 1)
- Q(s) = Qc*(s)*f(s) = [[(15s +1) (3s + 1)] / (9s + 1)] * [1 / (lem . s + 1)]
- f(s) = 1 / (lem * s + 1)
- y(s) = Q(s). P(s).r(s) = P*(+)(s) . f(s). r(s) •   Response variable:

  y(s) = {[-9s + 1] / [(15s +1) (3s + 1)]} * r(s)

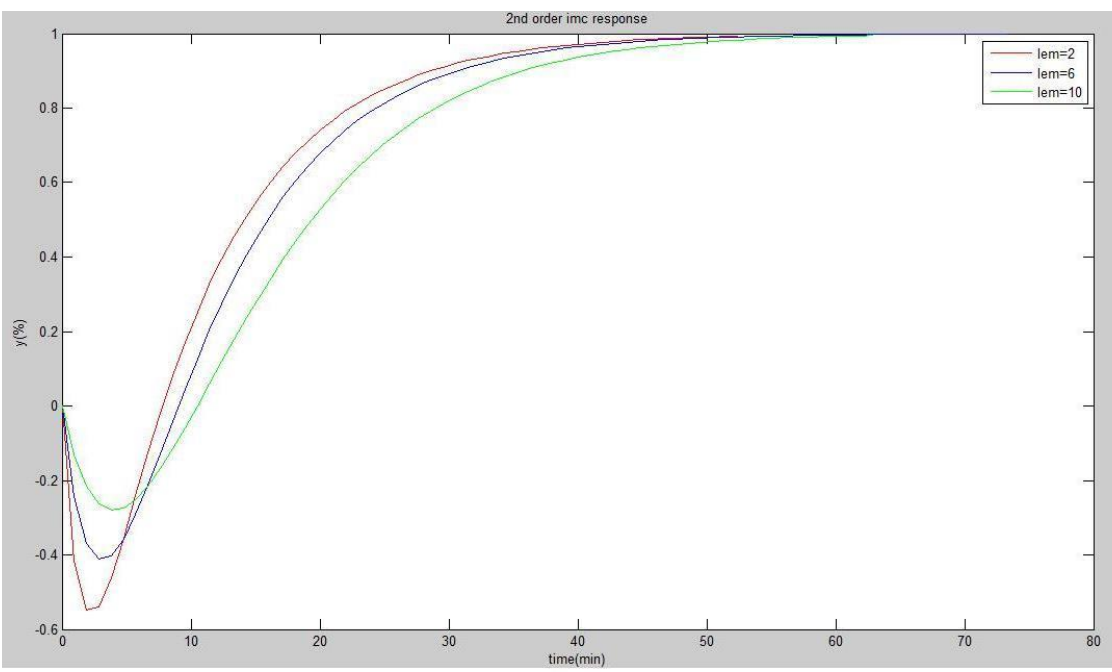
  = [-9s+1] / [9 lem s^2 + (9 +lem) s +1]

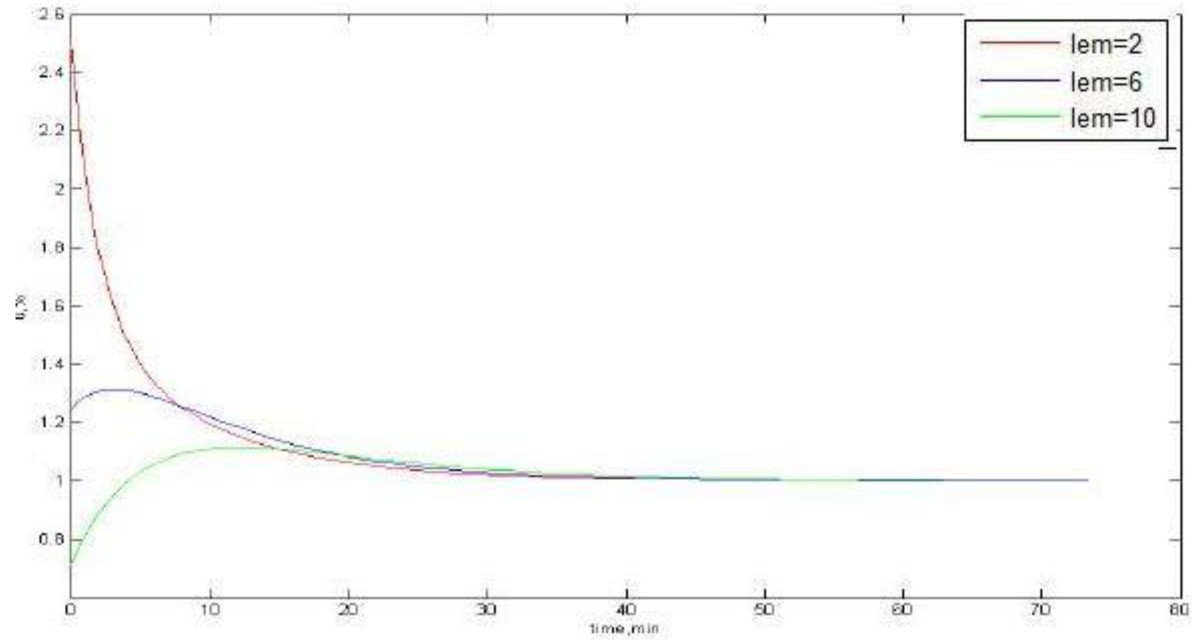
- Manipulated variable:

  u(s) = Q(s) * r(s) = {[[(15s +1) (3s + 1)]/[(9s + 1)(lem . s +1)]]}*. r(s)

  =[[(45 s^2 + 18 s +1)/ ((9 lem s^2 + (9 +lem) s +1))]] * r(s)

<u>2.4.1 Simulation plot for IMC 2nd order system a) Control variable response b) Manipulated variable output</u>




lem=2
lem=6
lem=10
time,min

CHAPTER 3

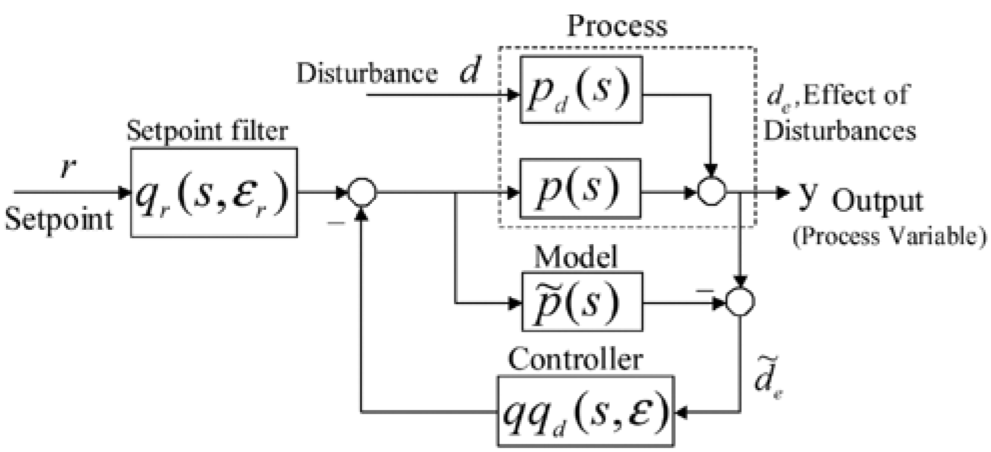
DESIGN OF 2DF IMC CONTROLLER

CHAPTER 3

3.1 Introduction

The controller $qq_d(s,e)$ in the figure providen below is programmed to ignore disturbances and the setpoint controller q(s,e) is programmed to form the response to setpoint changes. Henceforth, we will refer to the setpoint controller as the setpoint filter so as to be constant with industrial lexicon.

Figure 3.1. 2df imc controller block diagram



The response of the process

$$\tilde{p}_d(s) = p_d(s) = \tilde{p}(s) = p(s) = e^{-s}/(4s+1)$$

to disturbance function is:

$$y(t) = 0.274e^{-.25(t-2)} - 0.0526e^{-5(t-2)}; t \geq 2$$

The long tail in the response arises due to the zero 0.25 in the disturbance response. To remove this, we have to remove this zero using the controller. But then, the disturbance lag will badly damage the set point response. Hence, we use the 2DF IMC controller structure.

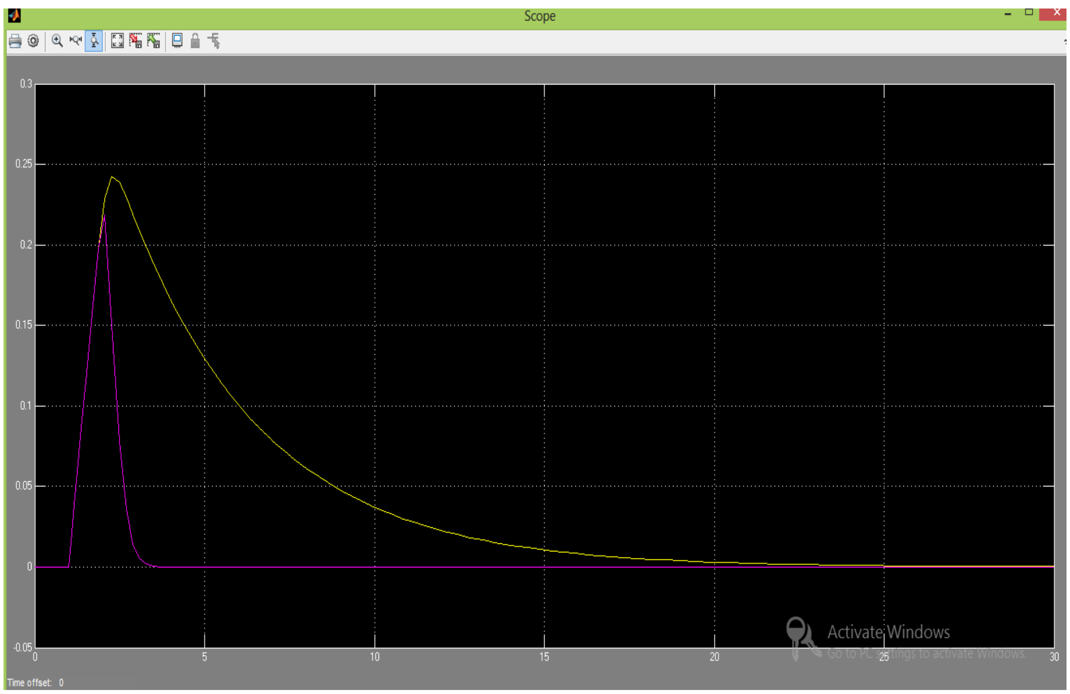
$$y(s) = \tilde{p}(s)q(s,\varepsilon_r)r(s) + (1 - \tilde{p}(s)qq_d(s,\varepsilon))p_d(s)d(s)$$

$$m(s) = q(s,\varepsilon_r)r(s) + qq_d(s,\varepsilon)p_d(s)d(s).$$

$$qq_d(s) = (4s+1)(1.19s+1)/(.2s+1)^2$$

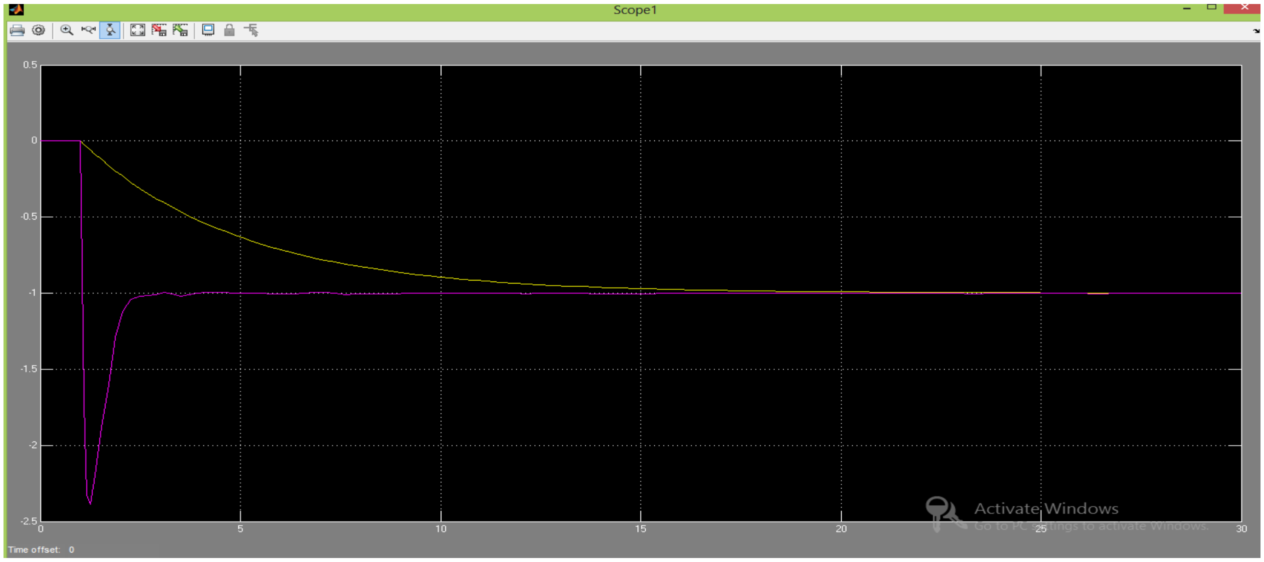
3.1. Simulation plot for IMC 2df IMC controller

a) Response variable response



The filter-time constant is 0.2. There is a significant development in the pace with which the disturbance on the response is removed.

b) Manipulate variable response



The better-quality output response needs a significantly more aggressive control effort.

3.2 Design of Setpoint Filter

The setpoint filter $q_r(s, e_r)$ is programmed like a single-degree of freedom controller. But, since there is mostly no noise on the setpoint, there is no noise amplification limit on e_r. Very minute values of e_r are not recommended due to of the possibility of control effort overload. Unless a model state feedback application is put in to use, minuteer filter-time constants can in fact cause slower response responses due to of control effort saturation. 1DF controller is programmed by inverting the invertible part of the process and adding necessary filter to make the controller be physically realizable. The choice of the filter parameter e depends on the allowable noise amplification by the controller and on modeling errors. To remove excessive noise amplification, the filter parameter e be picked so that the high frequency gain of the controller is less than 20 times its low frequency gain. For controllers that are ratios of polynomials, this condition can be expressed as:

$$\left|q(\infty)/q(0)\right| \leq 20$$

3.3 Design of 2DF Feedback Controller

The transfer function between response and disturbance for a perfect model is:

$$y(s) = (1 - \tilde{p}(s)qq_d(s,\varepsilon))\tilde{p}_d(s)d(s)$$

To design $qq_d(s,e)$ for a flawless model, it is suitable to study $qq_d(s,e)$ to be composed of two terms, $q(s,e)$ and $q_d(s,e)$. The design then continues as the following:

Choose $q(s,e)$. That is, $q(s,e)$ reverses a part of the process model

$$\tilde{p}(s)$$

Choose the controller filter as $1/(es+1)^r$, where r is the relative order of the part of the process model that is reversed by q(s, e).

Choose $q_d(s,e)$ as:

$$q_d(s,\varepsilon,\alpha) = \frac{\sum_{i=0}^{n} \alpha_i s^i}{(\varepsilon s+1)^n}; \quad \alpha_0 \equiv 1$$

Where n is the number of poles in the disturbance function to be removed by the zeroes of

$$(1-\widetilde{p}(s)qq_d(s))$$

$$(1-\widetilde{p}(s)qq_d(s))$$

Choose an experimental value for the filter-time constant e.

Calculate the values of a_i by explaining for each of the n separate poles of

$$\widetilde{p}_d(s)$$

which are to be taken out from the disturbance response.

$$(1-\widetilde{p}(s)qq_d(s,\varepsilon,\alpha))\Big|_{s=-1/\tau_i} = 0; \quad i = 1, 2, \ldots n$$

where t_i is the time constant connected with the i^{th} pole of disturbance function. If any of the poles are seen in complex conjugate pairs, then both the real and imaginary parts of equation are set to zero for one of the complex conjugate pairs. The set of equations providen are linear in the parameters a_i, no matter whether any of the poles of the disturbance function are real or complex. If disturbance function contains repeated poles, then the derivatives are set to zero, up to order one less than the number of repeated poles.

Adjust the value for e, and repeat step 4 till the required noise amplification is achieved. A few trials are usually enough to attain a noise amplification factor near the required value.

BASIC PRINCIPLE BEHIND DESIGN:-

The controller $qq_d(s,e)$ is programmed so as to ignore disturbances and the setpoint controller q(s,e) is programmed to provide form to the output to setpoint changes. The controller to ignore the disturbance is programmed in such a way that it removes the poles of the output response to the disturbance.

3.4 Design for Proper Noise Amplification Factor

The controllers are:-

$$q(s) = (4s+1)/(.2s+1)$$

$$q_d(s) = \frac{(\alpha s+1)}{(\varepsilon s+1)}.$$

To get the value of a:-

$$(1-\tilde{p}(s)qq_d(s,\varepsilon,\alpha))\Big|_{s=-1/4} = \left(\frac{1-(-\alpha/4+1)e^{1/4}}{(\varepsilon s+1)}\right) = 0$$

Choosing e = 0.2 in Eq. provides a = 1.189

The response is:-

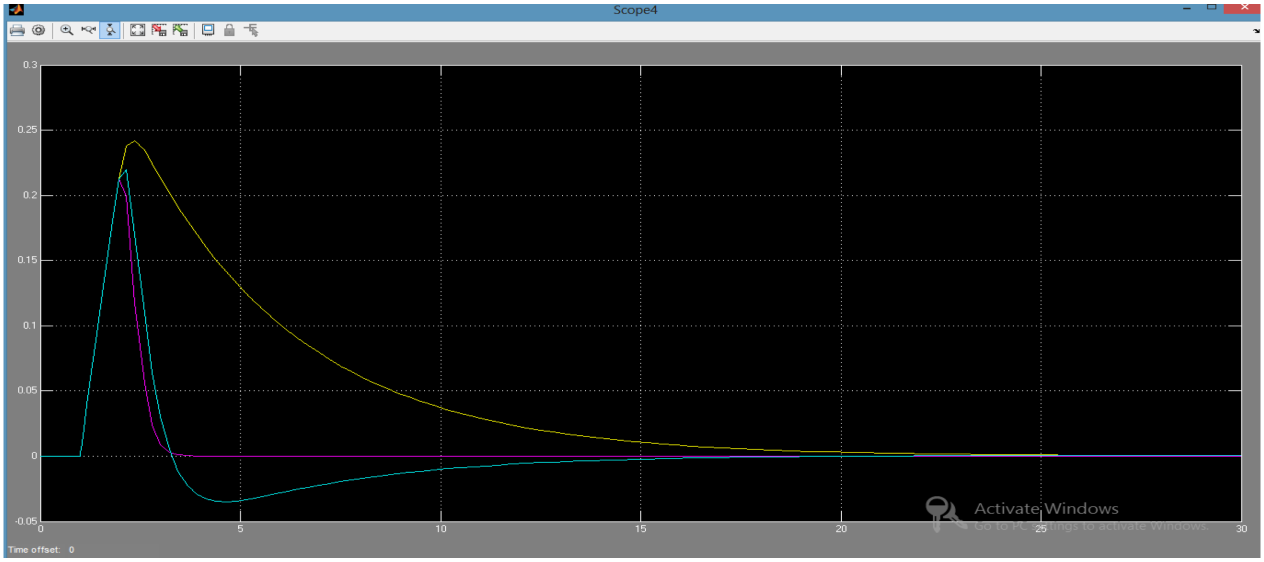
$$y(s) = \left(\frac{1}{s} - \frac{1}{s+.25}\right)e^{-s} - \left(\frac{1}{s} - \frac{1.301}{(s+.5)^2} - \frac{.2213}{(s+5)} - \frac{.7787}{s+.25}\right)e^{-2s}.$$

Inverting above Eq. and collecting terms for t>=2:-

$$y(s) = \left(\frac{1}{s} - \frac{1}{s+.25}\right)e^{-s} - \left(\frac{1}{s} - \frac{1.301}{(s+.5)^2} - \frac{.2213}{(s+5)} - \frac{.7787}{s+.25}\right)e^{-2s}.$$

The coefficient of $e^{-.25(t-2)}$ can be done minute by taking more important figures in a. For e = .2 and a = 1.189, the noise amplification factor is 119. Hence, this filter-time constant is way too minute. Calculating for a filter-time constant, e, and a, that satisfies the noise amplification, provides e = .59 and a = 1.736. The output of the process response to a step disturbance going in through $p_d(s)$ is illustrated. Visibly, amplifying noise by less than a factor of 20 has misplaced few of the merits of the two-degree of freedom control system. But, a settling time of 6 time units is even then much more suitable than a settling time of 20 time units.

<u>3.4. Simulation plot of 2df IMC controller for different filter parameter</u>



Amplifying noise by less than a factor of 20 gives up some of the merits of the two-degree of freedom control system. Even then, a settling time of 6 time units is much better than a settling time of 20 time units.

3.5 A Lead Process

The process is:-

$$p_d(s) = p(s) = \frac{(2s+1)e^{-s}}{(s+1)^2}.$$

1DF Controller is:-

$$q(s) = \frac{(s+1)^2}{(2s+1)(.025s+1)}$$

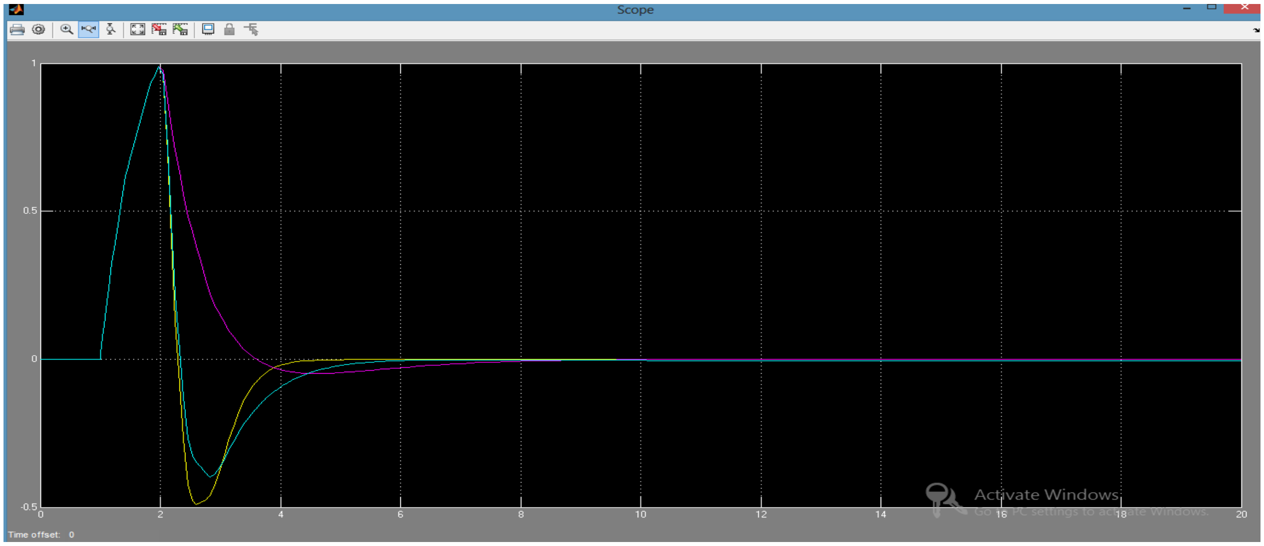
(a two-degree of freedom controller to eliminate the direct term of the disturbance lag (i.e., 2s + 1))

2DF Controller is:-

$$qq_d(s) = \frac{(s+1)^2(0.969s+1)}{(2s+1)(0.156s+1)^2}$$

(a two-degree of freedom controller to eliminate both disturbance lags (i.e., $(s + 1)^2$))

3.5 2df imc controller for lead process



This illustration shows that for a lead process (one whose frequency response firstly increases before ultimately decreasing), there is no benefit of using a 2DF over 1DF control system.

3.6 Underdamped Process

Process transfer function:-

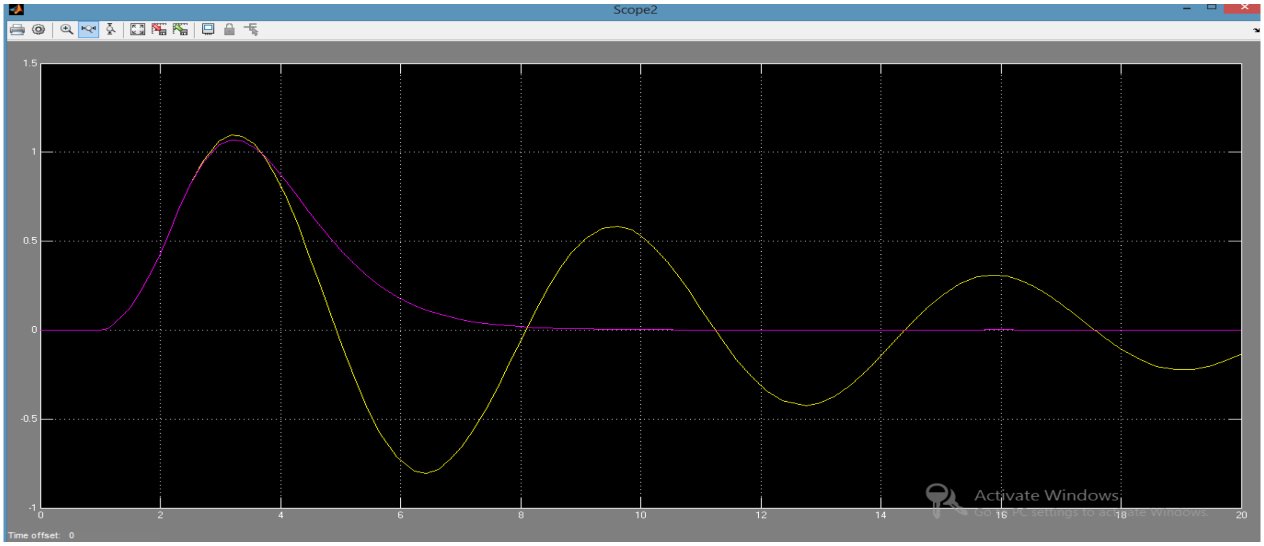
$$p_d(s) = p(s) = e^{-s} / (s^2 + .2s + 1)$$

Controller:-

$$q(s) = \frac{(s^2 + .2s + 1)}{(.22s + 1)^2}$$

$$qq_d(s) = \frac{(s^2 + .2s + 1)(2.4s^2 + .32s + 1)}{(.6s + 1)^4}$$

3.6 2df imc controller response for underdamped process



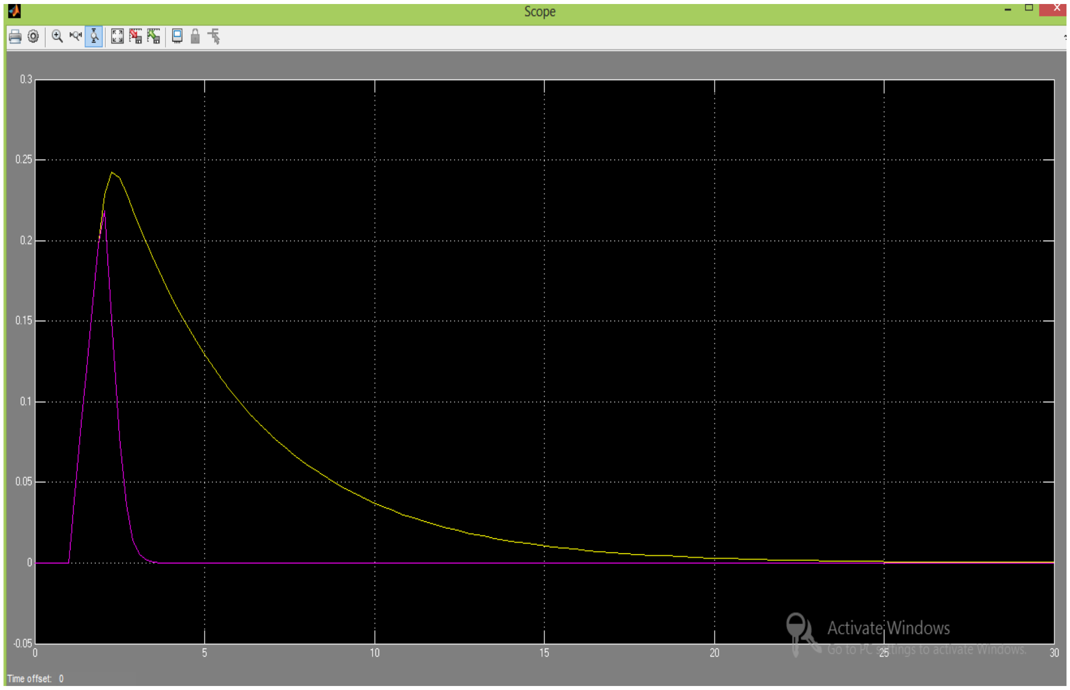
The response of the 2df control system is clearly much superior to that of the 1df system.

CHAPTER 4:

RESULTS

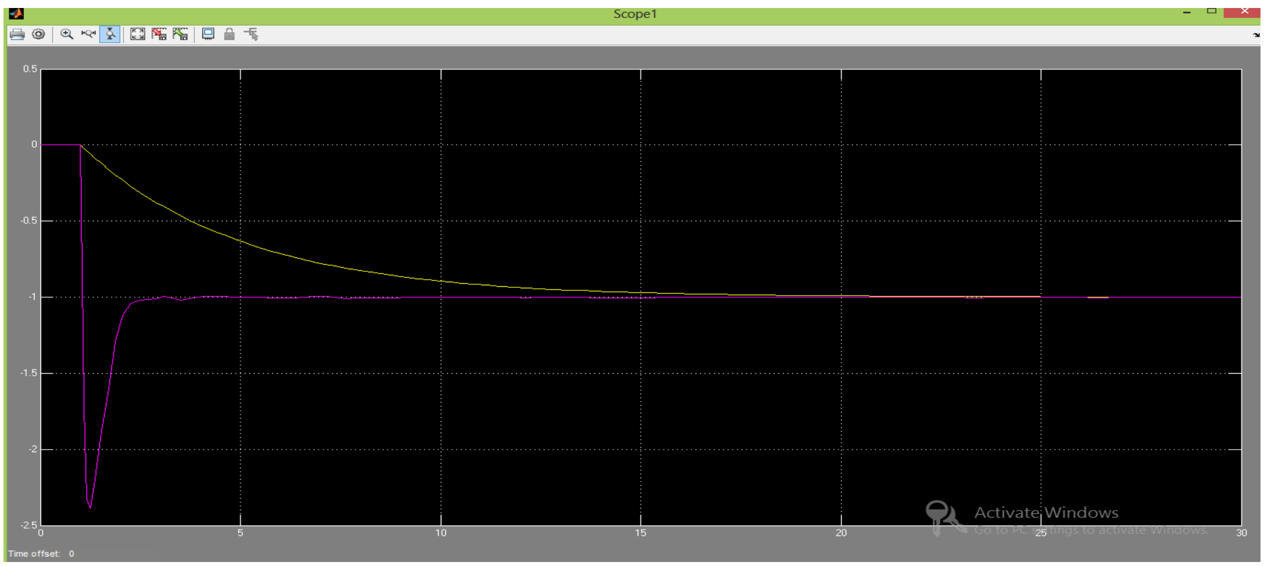
4.1. Simulation plot for IMC 2df IMC controller

a) Response variable response



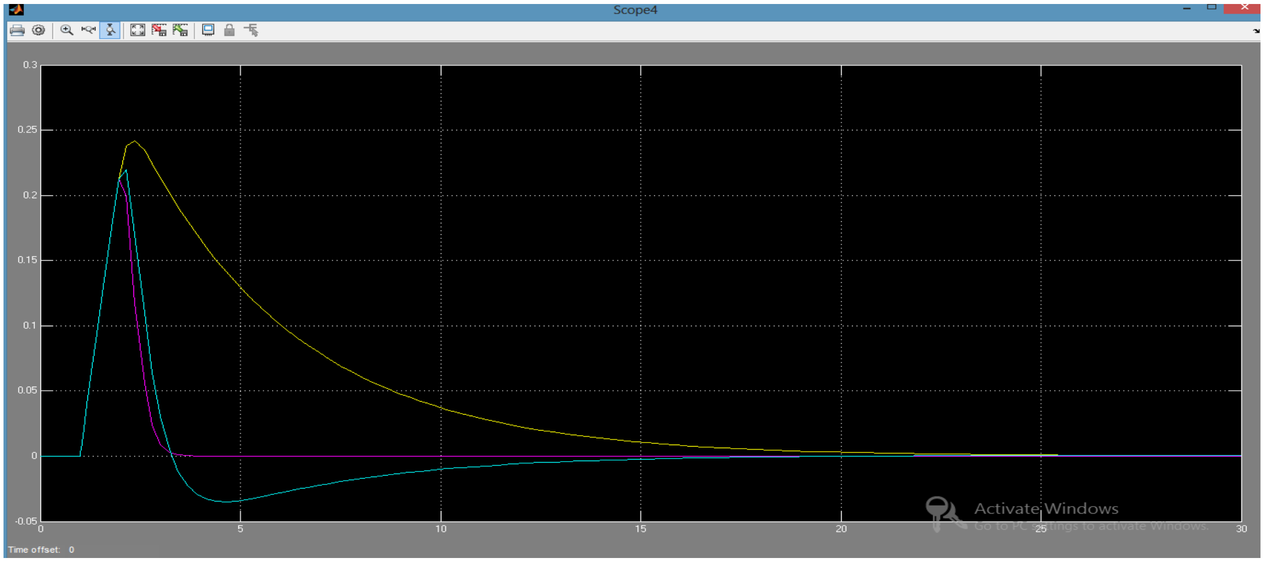
The filter-time constant is 0.2. There is a significant development in the pace with which the disturbance on the response is removed.

b) Manipulate variable response



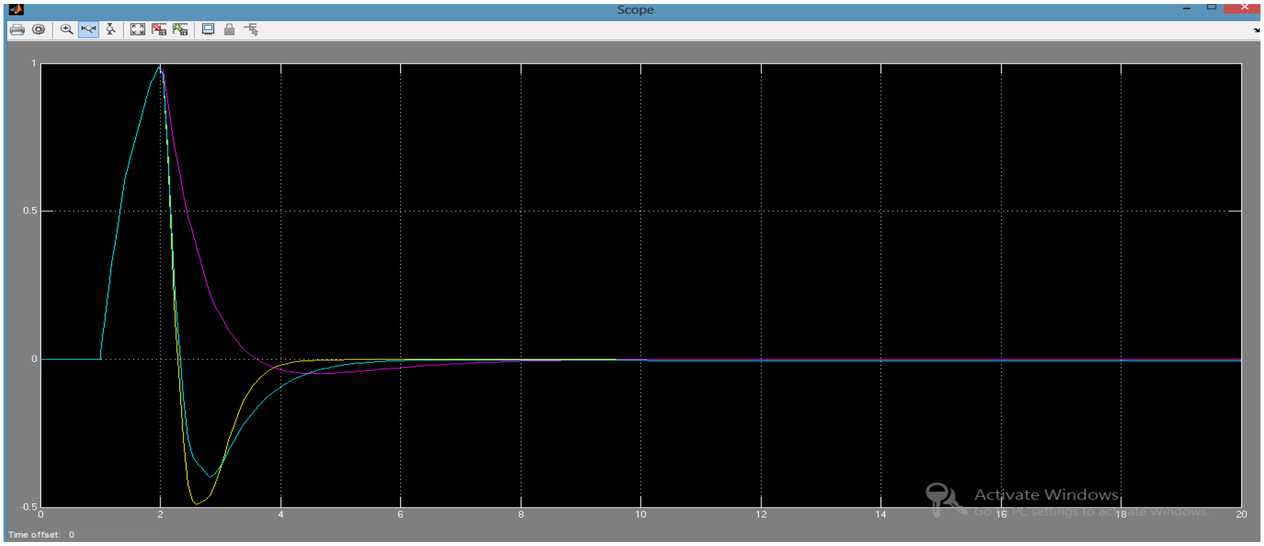
The better-quality output response needs a significantly more aggressive control effort.

4.2. Simulation plot of 2df IMC controller for different filter parameter



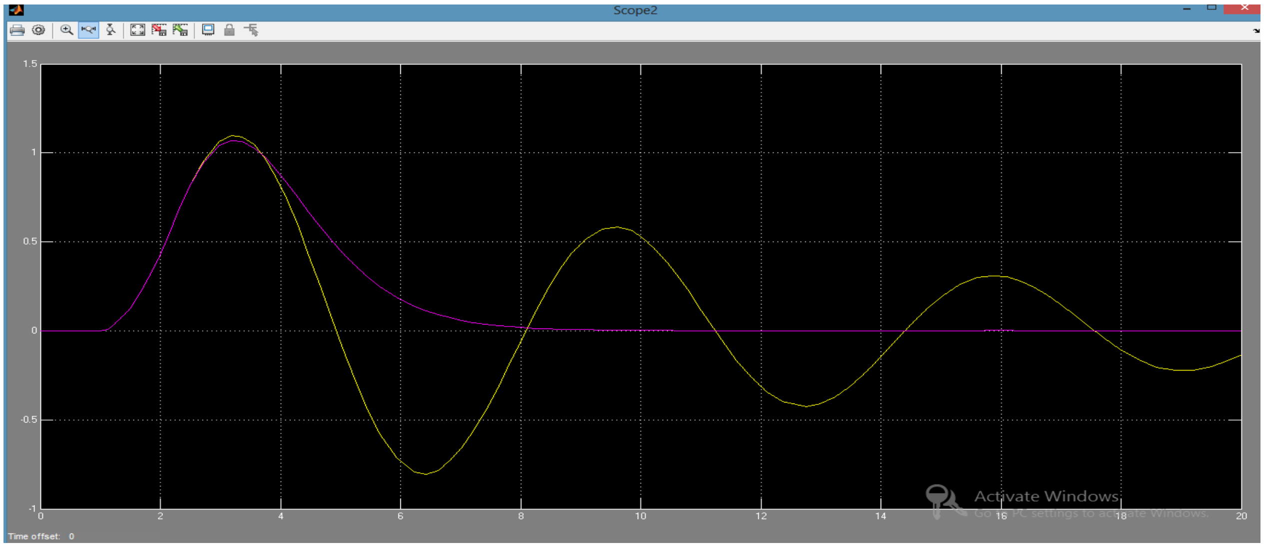
Amplifying noise by less than a factor of 20 gives up some of the merits of the two-degree of freedom control system. Even then, a settling time of 6 time units is much better than a settling time of 20 time units.

4.3 2df imc controller for lead process



This illustration shows that for a lead process (one whose frequency response firstly increases before ultimately decreasing), there is no benefit of using a 2DF over 1DF control system.

4.4 2df imc controller response for underdamped process



The response of the 2df control system is clearly much superior to that of the 1df system.

CONCLUSION

2DF IMC controller is useful for disturbance rejection. But for some processes 2DF is not advantageous over 1DF IMC controller. So for designing 2DF IMC controller we have to compare the 1DF and 2DF responses and choose the best controller. While designing the controller we should choose the filter parameters such that the noise amplification factor should not be more than 20.

FUTURE WORK

Tuning of 2DF IMC controller to take care of model uncertainty.

REFERENCES

- Techniques of mode by Coleman Brosilow, Babu Joseph
- Process control modeling design and simulation by B. W. Bequette
- Process dynamics and control By Dale E Seborg, Mellichamp and Edgar
- M. Shamsuzzoha, Moonyong Lee* Jietae Lee1-
- School of Chemical Engineering and Technology, Yeungnam University Chemical and Process Engineering
- UNIVERSITY OF NEWCASTLE UPON TYNE Morari, M.,and E. Zafiriou, Robust process control(1989)
- “Improved filter design in internal model control” by C.J.Gombas, R.D.Braatz (1996)
- “Algorithmic Internal Model Control” by R. Berber, C. Brosilow
- “Model predictive control of Unstable system” by C. Brosilow, C.M.Chang.
- Robust process control by M. Morari, F. Zafiriou.

References from internet:

- http://www.pdfqueen.com
- http://www.sciencedirect.com/
- http://books.google.co.in/
- http://www.mathworks.com/
- www.topedu**sites**.com/
- www.rpi.edu/
- www3.interscience.wiley.com
- journals.cambridge.org
- http:// cheer.sdsu.edu
- lorien.ncl.ac.uk
- http://ftp.math.hkbu.edu.hk
- http://yeungnam.academia.edu/nuvan/Papers
- http://www.waljatcolleges.edu.om/Downloads/PDFs/Project%20Format.doc
- http://ieeexplore.ieee.org/xpls/abs_all.jsp?isnumber=29279&arnumber=1322132&count=19&index=13
- http://doi.ieeecomputersociety.org/10.1109/ISDA.2006.30
- http://www.swarthmore.edu/NatSci/echeeve1/Ref/LPSA/PartialFraction/PartialFraction.html
- http://www.swarthmore.edu/NatSci/echeeve1/Ref/LPSA/PartialFraction/PartialFraction.html
- http://ecce6.kt.dtu.dk/cm/cont
- https://www.wikipedia.org/

- www.bgu.ac.il/
- ethesis.nitrkl.ac.in/1806/